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# AIRFLOW VERSUS PRESSURE DROP FOR BULK LATHYRUS GRAIN

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**ABSTRACT**

*Resistance of material to airflow is an important factor to consider in the design of a dryer or an aeration system. The airflow resistance of lathyrus was determined with the modified airflow resistance apparatus. It was found that pressure drop increased with increase in airflow rate, bulk density, bed depth and decreased with moisture content. Modified Shedd's equation, Hukill and Ives equation and modified Erguns equation were examined for pressure drop prediction. Airflow resistance was accurately described by modified Shedd's equation followed by Hukill and Ives equation and modified Erguns equation. The minimum fluidization velocity values were found decreased with increase in moisture content and bulk density. The developed statistical model comprised of airflow rate, moisture content and bulk density could fit pressure drop data reasonably well.*

***K eywords: Airflow Resistance, Pressure Drop, Lathyrus, Models***

## I. INTRODUCTION

The lathyrus (*Lathyrus sativus* L.) is food, feed and fodder legume (pulse) crop. It is grown on an area of about 1.5 million hectares with the annual production of 0.8 million tonnes. Nearly two-third of national acreage under lathyrus is in southeastern Madhya Pradesh, and in the *Vidarbha* region of Maharashtra. India ranks first in area (1500 thousand ha), production (800 thousand tonne) and productivity (533 kg $ha^{-1}$) [1].

The relationship between a drop in pressure and the rate of airflow through an agricultural product is important in the design of drying or aeration systems. Resistance to airflow is a function of both product and air properties [2]. The air pressure, required to force air through a bed of grain, is dissipated continuously due to friction and turbulence. The pressure drop for airflow through any particulate system depends on the rate and direction of airflow, surface and shape characteristics of the grain, the number, size and configuration of the voids, the particle size range, bulk density, depth of product bed, method of filling bin, fines concentration and moisture content. The data on the airflow-static pressure relationship of a number of agricultural grains have been published in the research documents. Most of researchers have reported airflow resistance data for agricultural grains but for low ranges of airflow. The data on airflow resistance of agricultural crops are scarce for high airflow range as reported by [3]

The phenomenon of pressure drop in airflow through agricultural products has been widely investigated for various grains [4]and root vegetables and other crops [5], [6] and [7]. In most cases, data were analyzed by

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means of equations [8] and [9]. Both the models have been widely used because they found to fit many experimental data sets. However, the constants in these equations have a purely empirical nature without physical meaning. An alternative expression is the model of [10] originally developed for packed beds of uniformly sized spheres; the equation contains a linear and a quadratic velocity term, which depends on bed porosity, particle diameter and fluid properties. Till date the safe maximum drying airflow rate for most of the agricultural grains are not yet reported in the literature. From the review of literature it revealed that the data on minimum fluidization velocity for lathyrus grain is non - existent. For most of the studies reported so far, it seems that airflow rate considered is not based on the scientific data leading to arbitrary selection of the airflow rate. Because of this situation, if the pressure drop data for complete static bed condition i.e. upto the minimum fluidization velocity condition is made available, then the selection of the blower will be more feasible at any level.

Earlier reported studies on airflow resistance of different agricultural grains as affected by various operating parameters were reviewed which showed that no design data on the resistance to airflow of lathyrus is available. Therefore, it is felt necessary to generate and provide data on airflow resistance of lathyrus to designers of drying systems for proper design of drying equipments. Therefore, the present investigation was planned with the following objectives:

(1) To determine pressure drop and minimum fluidization velocity at different airflow rates through the clean grain beds of lathyrus at different levels of moisture content and bulk density.
(2) To compare suitability of mathematical relationships available for pressure drop prediction with the experimentally determined data.
(3) To develop a statistical model describing the relationship between airflow resistance and the various operating parameters for lathyrus.

## II. MATERIALS AND METHODS

**2.1 Selection of Models** In order to interpret the results, modified Shedd's equation, Hukill and Ives equation and modified Ergun's equation were assessed for their fitness. The constant A of Shedd's equation takes into consideration the factors such as shape, surface roughness of grain etc. which are difficult to measure. Shedd's equation is:

$$V = A \, \Delta P^{B} \qquad (1)$$

Where,

V = airflow rate, $m^3 s^{-1} m^{-2}$

ΔP = pressure drop Pa $m^{-1}$ and

A and B = constants for a particular grain.

Another equation was proposed to represent the Shedd's data and also to take care of the non-linearity of experimental data on a log-log plot. This equation has been recommended by [11].

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$$\Delta P = \frac{AV^2}{\ln(1+BV)} \qquad (2)$$

Where,

$\Delta P$ = pressure drop, Pa $m^{-1}$,

V = airflow rate, $m^3\ s^{-1}\ m^{-2}$ and

A and B = product constants.

Modified forms of Ergun equation was also selected because it takes into account the important factor such as bed porosity, which is the most important factor for airflow resistance in packed bed. Modified forms of Ergun equation is:

$$\Delta P = AV \frac{(1-\varepsilon)^2}{\varepsilon^3} + BV^2 \frac{(1-\varepsilon)}{\varepsilon^3} \qquad (3)$$

Where,

$\Delta P$ = pressure drop, Pa $m^{-1}$,

V = airflow rate, $m^3\ s^{-1}\ m^{-2}$,

$\varepsilon$= bed porosity, decimal, and

A and B = product constants.

### 2.2 Minimum Fluidization Velocity

The flow rate at which the particles of the static bed cause incipient fluidization is known as minimum fluidization velocity. The total grain bed depth filled was 300 mm and pressure drop measurements were measured for the bed depth of 200 mm only. The experiments were carried out starting from lowest airflow rate and subsequently increasing it till the bed causes incipient fluidization which was recorded as minimum fluidization velocity. The effect of the moisture content and bed density levels on minimum fluidization velocity has been also studied.

The modified airflow resistance apparatus developed at the department was used for conducting the experiments on pressure drop and minimum fluidization.

The test bed was filled by a loose fill method as described by [12].To obtain medium and dense packed bed conditions, initially, a required quantity of test sample was loosely filled and then the bulk density was gradually increased to the desired level by tapping the side walls with rubber hammer. After filling the test bin the top surface of the grain bed was leveled manually by using stroker

At each airflow rate, the test run with five sets of observations were conducted at each bulk density level. The tests were carried out starting initially from highest airflow rate and subsequently by proceeding to lowest airflow rates. The system was tested for air leakage for pressures upto 16 kPa using soap solution at all joints before start of each experiment. The velocity measurement was repeated after reloading of the grain bed for each replication. Relative humidity, atmospheric pressure and temperature were measured five times during each test run and the average were used for airflow rate calculations to standard condition of air at temperature

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(32.5 °C) and pressure (101.325 kPa). The experiments were carried out at three different bulk densities for each moisture levels and for three bed depths (200, 400 and 600 mm). The experiments were carried out at all possible airflow (Nineteen airflow rates ranged from 0.0484 to 1.1693 $m^3 s^{-1} m^{-2}$) ranges.

For fitting the experimental data to the selected models, the entire span of airflow rates was considered as singular continuous airflow range and sub-divided into three sub-ranges of airflows to obtain more close results. These sub-ranges of airflows, viz., low, medium and high were selected based on the physical observation of three prominent straight line segments with different slopes obtained in the log-log plot between airflow rate and pressure drop. Fitted parameters (constant A and B), coefficient of determination ($R^2$) and standard error of estimate ($S_y$) were used to compare the relative goodness of fitting the experimental data with these models. The standard error of estimate expressed the average deviation between experimental and predicted values. Acceptability of the models for predicting the pressure drop was decided on the basis of percent data falling in different ranges of standard error of estimates.

The experimental data of lathyrus grain at each moisture and bulk density level were fitted to the selected three models by using non-linear least squares regression with MATLAB 7.1. The constants A and B for each of the model were estimated with multiple non-linear regression analysis technique using least square iterative procedure while fitting the experimental pressure drop values at each moisture level. The method of non-linear regression analysis was used to develop a statistical model to predict pressure drop across lathyrus grain by using the MATLAB 7.1.

## III. RESULTS AND DISCUSSION

In order to interpret the results, three models, viz., modified Shedd's equation (equation 1), Hukill and Ives equation (equation 2) and modified Ergun's equation (equation 3) were used and hereinafter referred as Model I, II and III, respectively. The equations were fitted with mean pressure drop data recorded with 600 mm grain bed depth for complete airflow range as well as three sub-ranges of airflows. To study the comparative behavior of these three models, the estimated constants (A and B) along with coefficient of determination ($R^2$) and standard error of estimate (Sy) of the equation were estimated for complete airflow and three sub-ranges of airflows. The data and estimates have been presented in Table 1. It was considered that full airflow as critical range; all the coefficient of determination of the equations was higher than 0.9987 for full airflow range of $0.0484 \leq V \leq 1.1693$ $m^3 s^{-1} m^{-2}$. Therefore, the magnitudes of standard error of estimates were utilized for comparing the relative precision of the models to predict airflow resistance of lathyrus. The average Sy values (mean values at three moisture levels) obtained by the models for complete airflow ranges with loose, medium and dense packed grain conditions were compared. For three sub-ranges of airflows, the average Sy values for only loose fill grain bed conditions were considered.

It can be noted from Table 1 that for the complete airflow range ($0.0484 \leq V \leq 1.1693$ $m^3 s^{-1} m^{-2}$), average values of standard error of estimate for loose fill condition were 95.90, 98.00 and 110.02 Pa $m^{-1}$ with model I, II, III, respectively. For sub-ranges of airflows of $0.0484 \leq V \leq 0.3675$ , $0.3675 < V \leq 0.7638$ and $0.7638 < V \leq 1.1693$ $m^3 s^{-1} m^{-2}$ the average standard error of estimate values for loose fill conditions were found to be 58.64, 51.38, 50.64; 46.56, 46.82, 48.53 and 30.26, 34.40, 39.46 Pa $m^{-1}$, respectively for model I, II and III. These results

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indicated that for the purpose of predicting pressure drop in loosely filled condition in these sub-ranges of airflows all the models were at par for predicting pressure drop.

While comparing for acceptability of these three models, the results indicated that for lathyrus grains 93% acceptable data sets were within ±1 Sy limit, and 7% in ± 2 Sy limit for model- I. It was 74% in ±1Sy limit; 15% in ± 2 Sy limit and 11% in ± 3 Sy limit for model- II whereas, these data sets were 56, 32 and 12% in ±1Sy, ± 2 Sy and ± 3 Sy limit for model- III.

Hence, all these three models were acceptable for predicting pressure drop through lathyrus grains within the experimental airflow range of the study. This indicated that the modified Shedd's equation is a better choice for predicting pressure drop through bulk lathyrus grain beds followed by Hukill's and Ives equation and modified Erguns equation. Similar results were reported for pulse grains [4] and for beds of apples [6].

The method of non-linear multiple regression analysis using least squares procedure was used to describe the relationship between pressure drop across lathyrus grain bed, airflow rate, bulk density and moisture content. For the specified grain conditions, the predicted pressure drop based on the equation 4 would help in selection of the blower for pulse dryer design. Values of experimental pressure drop were regressed against each and all possible combinations of these variables in a step-wise approach. This technique allowed testing of the statistical validity of including each of the variables as a component of the model predicting airflow resistance. The results showed that with inclusion of each of the variables in the pressure drop predicting model, the value of $R^2$ was significantly increased whereas, the Sy value was decreased for the three sub-ranges from low to high level. The best fit values of coefficient $b_1$, $b_2$, $b_3$ and $b_4$ in the generalized form of a second degree polynomial were obtained and are shown in Table 2. The values of standard error of estimates were determined for judging the precision of the model. From the high values of coefficient of determination and percent data falling in $\pm$1 Sy limit, it was evident that the experimental data fitted the equation 4 reasonably well. The model that was found to describe airflow resistance was as follows:

$$\Delta P = b_1V + b_2V^2 + b_3VM + b_4V\rho_b \qquad (4)$$

Where, $\Delta P$ = pressure drop, Pa $m^{-1}$

$V$ = airflow rate, $m^3 s^{-1} m^{-2}$

$M$ = moisture content, % d.b.

$\rho_b$ = bulk density, kg $m^{-3}$ and

$b_1$, $b_2$, $b_3$, and $b_4$ = regression coefficients

In case of lathyrus it could be noted from the results as shown in Table 2 that for predicting pressure drop through the grain with the equation 4 the values of coefficient of determination for complete, low, medium and high airflow ranges were 0.9941, 0.9923, 0.9656 and 0.9860, respectively. In all cases the percent data were more than 96% upto $\pm$2 Sy limit. For lathyrus having moisture content ranging from 7.90 to 19.40% d.b., bulk density between 755 to 890 kg $m^{-3}$, and bulk porosity ranging between 30.34 to 39.23%; the model could predict pressure drop in the full airflow range ($0.0484 \leq V \leq 1.1693$ $m^3 s^{-1} m^{-2}$) with standard error of estimate of 247.1

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Pa m$^{-1}$ whereas, the values of standard error of estimate for the sub-ranges $0.0484 \le V \le 0.3675$, $0.3675 < V \le 0.7638$ and $0.7638 < V \le 1.1693$ m$^3$ s$^{-1}$ m$^{-2}$ were 37.75, 211.1 and 242.2 Pa m$^{-1}$, respectively.

The above results indicated that the statistical model was acceptable for prediction of pressure drop through lathyrus grain beds within the experimental limit.

### 3.1 Minimum Fluidization Velocity

The data obtained during the experiments conducted for determination of minimum fluidization velocity values for lathyrus grain at different moisture contents and bulk densities are discussed separately under following heads.

### 3.2 Effect of moisture content on fluidization

Results obtained showed that for loosely filled lathyrus grain bed at the moisture content of 7.90, 13.60 and 19.40% d.b. as shown graphically in Fig. 1; the minimum fluidization velocity values noted were found to be 1.5748, 1.4591 and 1.3236 m$^3$ s$^{-1}$ m$^{-2}$, respectively, with corresponding increase in moisture content.

With increase in moisture content the minimum fluidization velocity values were found decreased. The moisture content of grain beds were increased which might resulted change in void configuration along with increased grain surface contact area that have increase the needed airflow rate to cause incipient fluidization for grain with higher moisture content. Similar results have been reported for effect of moisture content on minimum fluidization velocity for various pulse grains; black gram [13] and for moth gram [3].

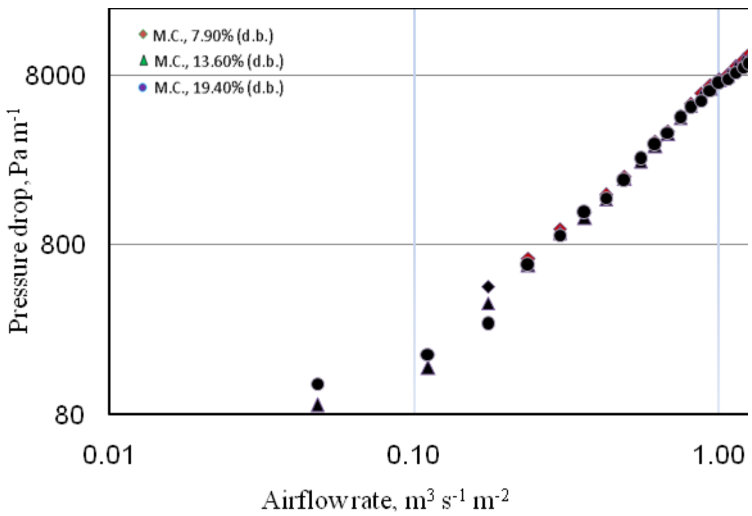


**Figure1: Effect of Moisture Content on Minimum Fluidization Velocity of Lathyrus at Different Moisture Contents in Loosely Filled Condition**

### 3.3 Effect of bulk density on fluidization

For loosely filled lathyrus grain beds with moisture content 13.60% d.b. and having bulk density of 775, 820 and 865 kg m$^{-3}$ as shown graphically in Fig. 2; the minimum fluidization velocity values recorded were 1.4591, 1.3339 and 1.1508 m$^3$ s$^{-1}$ m$^{-2}$, respectively.

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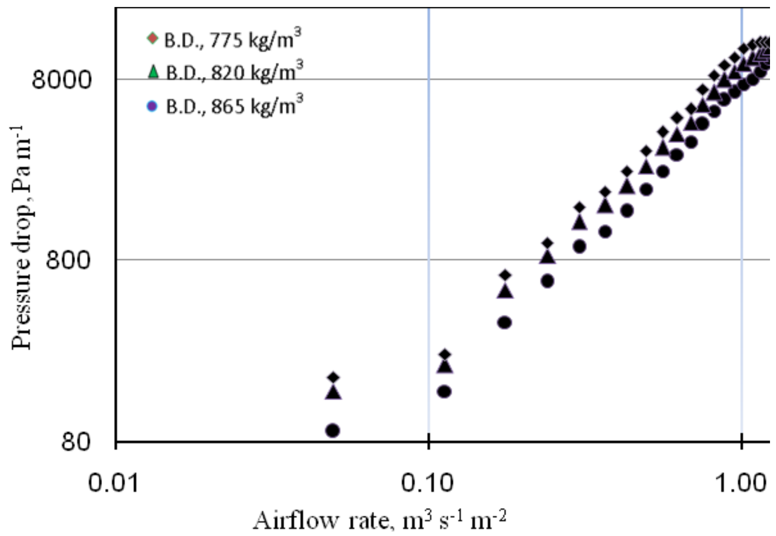


**Figure2: Effect of Bulk Density on Minimum Fluidization Velocity of Lathyrus at Moisture Content Of 13.60% D.B.**

With increase in bulk density from 775 to 865 kg $m^{-3}$, at the corresponding moisture content of 13.60 % d.b. the bulk porosity and grain surface contact area was decreased this resulted in the compaction of void configuration which might have lowered the needed airflow rate to cause incipient fluidization. Lowering the needed airflow rate might be due to the composite effect of increased moisture content with increased bulk density values. Similar results have been reported for effect of bulk density on minimum fluidization velocity for various pulse grains; black gram [13] and for moth gram [3]

## IV. CONCLUSIONS

1) Based on statistical analysis all the selected models were accurate enough for predicting pressure drop through lathyrus grain beds within the extremities. However, the modified Shedd's equation was more precise followed by Hukill and Ives and Modified Ergun equation.
2) Coefficient A of modified Shedd's equation was linearly related to the grain moisture content and it represented the change in moisture content.
3) The statistical model developed for predicting pressure drop through lathyrus as affected by airflow rate, bulk density and moisture content was found to fit the experimental data reasonably well.
4) For loose fill grain beds with the minimum fluidization velocity values were found decreased with increase in moisture content and bulk density.

## V. ACKNOWLEDMENT

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**Table1: Constant A and B in Various Models For Complete Range And Three Sub-Ranges of Airflows for Lathyrus mean values of five replications**

| model | A | B | $R^2$ | Sy | A | B | $R^2$ | Sy | A | B | $R^2$ | Sy | A | B | $R^2$ | Sy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $0.0484 \le V \le 1.1693$ ($m^3 s^{-1} m^{-2}$) | | | | $0.0484 \le V \le 0.3675$ ($m^3 s^{-1} m^{-2}$) | | | | $0.3675 < V \le 0.7638$ ($m^3 s^{-1} m^{-2}$) | | | | $0.7638 < V \le 1.1693$ ($m^3 s^{-1} m^{-2}$) | | | |
| Modified shedd | 6525 | 1.709 | 0.9988 | 95.90 | 3302 | 1.132 | 0.9769 | 58.64 | 7111 | 1.915 | 0.9984 | 46.56 | 6543 | 1.625 | 0.9996 | 30.26 |
| Hukill and Ives | 23680 | 36.75 | 0.9987 | 98.00 | 4362 | 1.98 | 0.9822 | 51.38 | 83870 | 13340 | 0.9983 | 46.82 | 16020 | 10.59 | 0.9995 | 34.40 |
| Modified Ergun | 240.53 | 501.00 | 0.9984 | 110.02 | 360.95 | 198.02 | 0.9827 | 50.64 | 58.28 | 677.58 | 0.9982 | 48.53 | 396.95 | 407.8 | 0.9993 | 39.46 |

**Table 2: Coefficient of an Estimated Multiple Regression Model (Equation 4) To Describe the Airflow Resistance of Lathyrus**

| Airflow range , ($m^3 s^{-1} m^{-2}$) | Regression coefficients | | | | $R^2$ | Sy |
|---|---|---|---|---|---|---|
| | $b_1$ | $b_2$ | $b_3$ | $b_4$ | | |
| | M = 7.90 - 19.40% (d. b.), BD = 755 - 890 $kg/m^{-3}$ and ε = 30.34 - 39.23% | | | | | |
| $0.0484 \le V \le 1.1693$ | -212444 | 5205 | 27.56 | 95.76 | 0.9941 | 247.1 |
| $0.0484 \le V \le 0.3675$ | -11074 | 6747 | 13.85 | 36.48 | 0.9923 | 37.75 |
| $0.3675 < V \le 0.7638$ | -14263 | 1183 | 26.32 | 101.15 | 0.9659 | 211.1 |
| $0.7638 < V \le 1.1693$ | -9155 | -2106 | 28.97 | 98.36 | 0.9860 | 242.2 |

**M = Moisture content %, BD = Bulk density and ε = Porosity**